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Improvement of the Japan Meteorological Agency Meso-Scale Model for the Forecasting the Photovoltaic Power Production: Modification of the Cloud Scheme

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Abstract

Power production of a photovoltaic (PV) power plant varies according to weather conditions. Therefore, it is important for the prediction of the PV power production to use the weather data (satellite data or numerical weather prediction, etc.). In our research group, for the day ahead forecasting, the output of the numerical weather model, Japan Meteorological Agency Meso-Scale Model (hereafter MSM) is used for the input of the PV power production model. From our previous research, the MSM forecast of the global horizontal irradiance (GHI) tends to be underestimated (overestimated) during summer (winter). Further investigation revealed that the error of the MSM GHI forecast is in a relation of the inverse correlation with the error of the MSM cloudiness forecast. So, in this study, to improve the MSM GHI forecast, the cloud scheme is modified to remove the error.

The MSM is an operational, non-hydrostatic and regional model used for a short-range forecast (33 hours). The model horizontal resolution is 5 km mesh and the model vertical resolution is 50 levels. The current cloud scheme of the MSM has the seasonal error so that the parameter which dependent on the surface air temperature is introduced to represent the seasonality: if the surface air temperature is low (high), then the cloud production is accelerated (decelerated). Twelve cases (6 for winter and 6 for summer) are chosen for the analysis.

The modified cloud scheme makes a success of the reduction of the MSM GHI forecast error. The daytime averaged root mean square error (RMSE) of the MSM GHI forecast for all cases is improved about 5% (from 120 W m² to 114 W m²). The daytime averaged mean bias error (MBE) of the MSM GHI forecast for all cases is significantly reduced from -14.3 W m² to -5.13 W m². For each cases, although three of them are increased the RMSE (about 3 W m²), the total trend are decreased the RMSE.

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1. Introduction

In order to achieve the low carbon society, the Japanese government has planned to introduce massive photovoltaic (PV) systems (53 GW by 2030). The power production of the PV system varies according to weather conditions. Therefore, in the case that PV systems are massively introduced to the power system, it is necessary for the stabilization of the power system to work out the supply-demand plan which takes account of the generation reserve margin such as the thermal power or the pumped-storage power generation, etc. The prediction of the power production of the PV system, which is necessary to make the supply-demand plan, is calculated by the engineering model such as heuristic or regression. The input of the engineering model is forecast meteorological parameters (irradiance or cloud amount, etc.) which are calculated by the output of the numerical weather model or the temporal extrapolation of the satellite data. Therefore, the accuracy of forecast meteorological parameters affects the prediction of the power production of the PV system and the supply-demand plan. Hence, it is important to figure out the accuracy of forecast meteorological parameters.

In order to make the power supply-demand plan, the start-and-stop plan of the generation reserve margin (thermal or pumped-storage power generation) is made by the evening of a day ahead so that it is necessary to predict the power production of the PV system by a day ahead. Therefore, it is necessary to forecast meteorological parameters by a day ahead. However, meteorological parameters forecasted by the temporal extrapolation of the satellite data keep their accuracy in few hours [1] so that meteorological parameters forecasted by the numerical weather model are used frequently. In our research group, the support vector machine (SVM) is used for the prediction of the power production of the PV system [2]. The input of the SVM is the output of the numerical weather model, the Japan Meteorological Agency Meso-Scale Model (MSM) [3]. Forecast meteorological parameters calculated by the MSM are used for the prediction of the power production of the PV system not only in our research group but also in several other research groups [4] [5] so that it is important to figure out and improve the forecast accuracy. Therefore, there are several researches to validate the accuracy of the forecast irradiance by the MSM. The MSM forecast of the global horizontal irradiance (GHI) is overestimated /underestimated in winter/summer [6] and the error of the MSM GHI forecast is in a relation of the inverse correlation with the error of the MSM cloud amount forecast [7]. Hence, the accuracy of the MSM cloud amount forecast is one of the quite important factors for the accuracy of MSM GHI forecast.

In this study, in order to improve the MSM GHI forecast, the MSM cloud amount forecast scheme associated with the irradiance forecast is modified to remove the error. The modification approach and improved results are shown in below sections.

2. Japan Meteorological Agency Meso-Scale Model

2.1. Aspect of Numerical Weather Model and MSM

The numerical weather model basically consists of the momentum equation, thermodynamic equation and equation for conservation of mass and predicts future meteorological parameters calculated by the time integral of above equations under given initial conditions. “Meso” means the scale of the phenomenon: from few thousands kilometers to few kilometers. MSM targets the meso-scale phenomena and forecasts disaster (heavy rain and high wind) from few hours to a day in advance.

The MSM is an operational, non-hydrostatic and regional model. The computational domain of the

MSM (Fig. 1) is 3600 km in longitudinally and 2900 km in meridionally, and the horizontal resolution is 5 km mesh. The vertical resolution is 50 levels and the layer interval is smaller in the low levels (40 m at the lowest level) and larger in the high levels (1 km at the highest level). Therefore, the MSM can reproduce growth and decay of phenomena three-dimensionally. Because of the computational cost, the calculation of the MSM irradiance, which is calculated by the radiation process (be discussed below), is conducted at 10 km and 15 minutes intervals. The MSM calculation is executed 8 times in a day and 4 calculations forecast 15 hours in advance (started at 03, 09, 15, 21JST, Japan Standard Time, UTC + 9 hours) and the other 4 calculations forecast 33 hours in advance (started at 00, 06, 12, 18JST).

The MSM irradiance is calculated by the radiation process. The radiation process calculates the absorption and diffusion of the solar radiation in the atmosphere. GHI is corresponding to the downward shortwave radiation at the surface. The radiation process can be separated by two parts. One calculates the effect of the aerosols which absorb and diffuse the solar radiation, the other calculates the effect of the clouds which also absorb and diffuse the solar radiation. The distribution of aerosols is given by climatic data which is estimated by the satellite data and the effect of aerosols is calculated based on above distribution. The distribution of clouds is given by the cloud process in the MSM and the effect of clouds is calculated based on the MSM forecast value. From previous researches, the MSM GHI forecast is affected by the MSM cloud amount forecast. In the following section, the cloud process of the MSM is described.

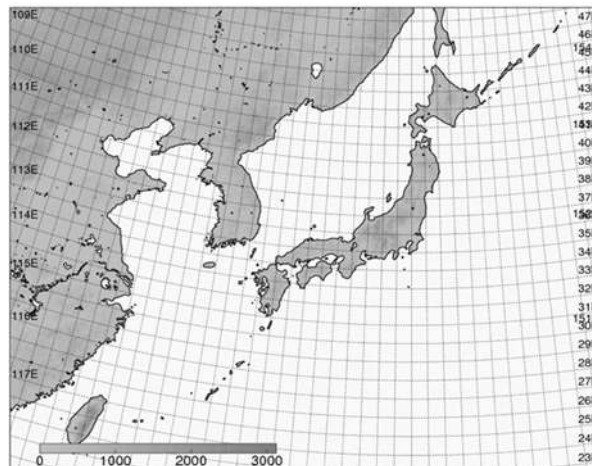


Fig. 1. Computational domain of MSM

2.2. Cloud Process of MSM

The MSM cloud process associated with the radiation process is called as the partial condensation scheme. In the MSM, cloud water, cloud ice, rain, snow and graupel associated with precipitation are calculated by the microphysics scheme. Although the horizontal resolution of the MSM is 5 km mesh, for the microphysics scheme, cloud water or cloud ice can be reproduced only when the whole of the mesh is saturated. Therefore, the microphysics scheme cannot reproduce partial clouds in the mesh so that the MSM cloud amount becomes underestimation. In the realistic case, there is the turbulence in the mesh so that if the whole of the mesh is unsaturated, clouds can exist partially. The partial condensation scheme expresses above partial clouds. In the MSM, cloud water and cloud ice calculated by this partial condensation scheme are used for the calculation of the effect of clouds in the radiation process.

In the MSM, the partial condensation scheme is based on Sommeria and Deardorff (1977) [8] [9]. In

this scheme, turbulence in the mesh is assumed by the normal distribution (standard deviation σ_s) and if the whole of the mesh is unsaturated but turbulence in the mesh is large, this partial condensation scheme allows the reproduction of cloud amount in the mesh. When the saturation specific humidity is set as q_s , cloud amount is defined as the probability that the total humidity mixing ratio, q_w , exceeds q_s . Figure 2 shows the difference of cloud amount to q_w between large σ_s case and small σ_s case in the MSM partial condensation scheme. If σ_s is large then cloud amount varies to q_w and when the whole of the mesh is unsaturated, cloud amount is expressed. While if σ_s is small then cloud amount varies in the vicinity of q_s and when the whole of the mesh is unsaturated, cloud amount is not expressed.

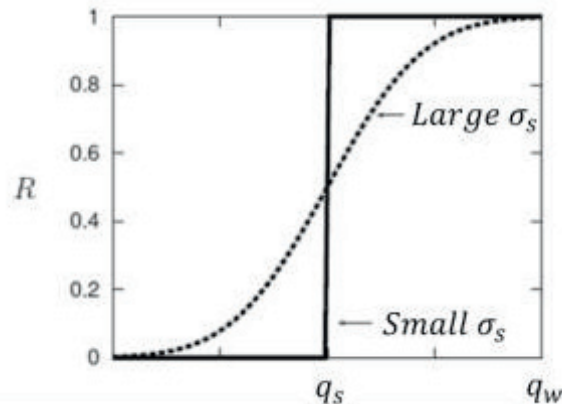


Fig. 2. Difference of cloud amount to q_w between large σ_s case and small σ_s case in the MSM partial condensation scheme (from Hara 2008) [9]

Although one of the generation processes of turbulence in the mesh is associated with the generation of the convective cloud, this turbulence is not considered in this partial condensation scheme. Therefore, in order to avoid that σ_s becomes too small, the adjustment parameter, f_{min} , is introduced. If f_{min} is large then the lower limit of σ_s becomes large and cloud amount is more likely expressed but cloud amount does not range around 0 or 1. In the MSM, f_{min} is set as 0.09. This value is chosen as the result from the test that the value of f_{min} is changed from 0.07 to 0.1.

3. Approach of the Modification of the MSM Cloud Process

3.1. Modification of the MSM Cloud Process

The MSM GHI forecast has the seasonal bias: underestimation in summer and overestimation in winter. This bias is the inverse correlation with the bias of the MSM cloud amount forecast: underestimation in winter and overestimation in summer. In order to remove the bias of the MSM GHI forecast, it is necessary to introduce a parameter which modifies the bias of the MSM cloud amount forecast. This bias has seasonality so that in the partial condensation scheme, we introduce the new f_{min} parameter in order to remove the bias.

In the MSM, f_{min} is set as constant value, 0.09, so that we introduce another 2 constant value experiment; one is the large f_{min} experiment (0.15, hereafter sgm_f0.15) and the other is the small f_{min} experiment (0.03, hereafter sgm_f0.03). Furthermore, we introduce the new f_{min} as a function of the ground temperature. There is no bias in spring and autumn so that if the ground temperature is 20 degrees C then f_{min} is 0.09 and if the ground temperature is higher/lower than 20 degrees C then f_{min} is linearly

decreased/increased. Three linearly-change experiments are executed (hereafter sgm_mod2, sgm_mod3, sgm_mod4, see Fig. 3). The lower limit of f_{min} is set as 0 and the higher limit of f_{min} is set as 0.15 in this case.

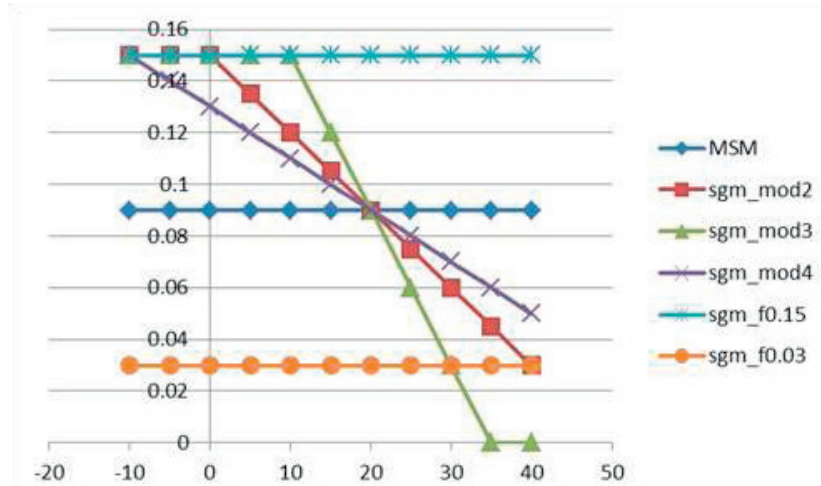


Fig. 3. Function of f_{min} to the ground temperature. The unit of X-axis is centigrade.

3.2. Validation Method of the MSM Forecast Accuracy

This study concerns the day-ahead power supply-demand planning so that we choose the initial time of MSM as 12JST. This MSM forecast covers 33 hours (until 21JST on the following day). The modified cloud scheme experiments are executed as the same settings as the MSM except for the cloud scheme.

For the validation of the accuracy of the forecast GHI, the daytime-averaged mean error (ME) and root mean square error (RMSE) is used. For the observed GHI, the data from 50 ground base GHI observation station in Japan is used. For the forecasted GHI, the averaged value of the nearest point from the observation station and surrounding 8 points (only used land mesh) is used. The averaged value of the whole observation points is used for the validation. Twelve cases (6 for winter 2010 and 6 for summer 2010) are chosen for the analysis.

4. Results

Figure 4 shows the all-averaged, winter-averaged and summer-averaged RMSE. For sgm_f0.03, the forecast accuracy is similar to the MSM in summer but is worse in winter so that the all-averaged RMSE is worse than the MSM. For sgm_f0.15, the result is opposite to sgm_f0.03; the forecast accuracy is better than the MSM in winter but is significantly worse in summer so that the all-averaged RMSE is worse. For sgm_mod2, sgm_mod3 and sgm_mod4, the forecast accuracy is better than the MSM in all season. For sgm_mod2, which is the best modification of the forecast accuracy, the all-averaged RMSE is improved about 5 % (from 120 W m^{-2} to 114 W m^{-2}).

Figure 5 shows the all-averaged, winter-averaged and summer-averaged ME. For the MSM, the all-averaged ME is small negative bias (-14.3 W m^{-2}). For sgm_f0.03, the averaged ME is large positive bias through all season. For sgm_f0.15, the winter-averaged ME is small negative bias but the summer-averaged ME is large negative bias so that the all-averaged ME is large negative bias. For sgm_mod2, sgm_mod3 and sgm_mod4, the averaged ME is smaller than the MSM through all season. In particular,

for sgm_mod2, although the averaged ME still has seasonally bias, the all-averaged ME is very small (-5.13 W m^{-2}).

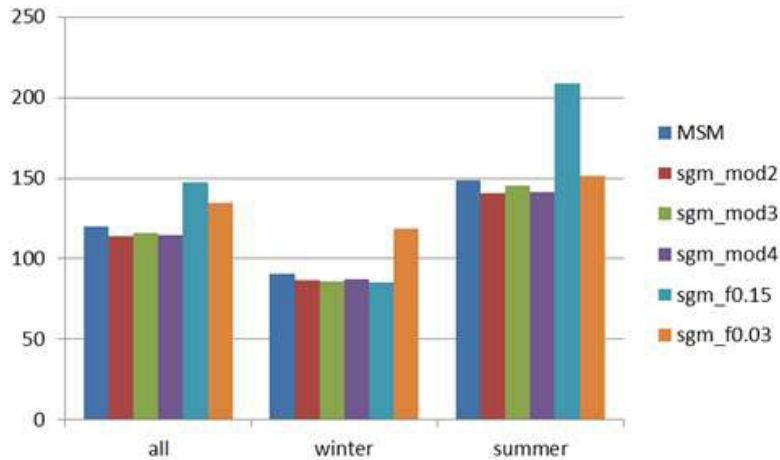


Fig. 4. The daytime averaged root mean square error (RMSE) of the MSM insolation forecast

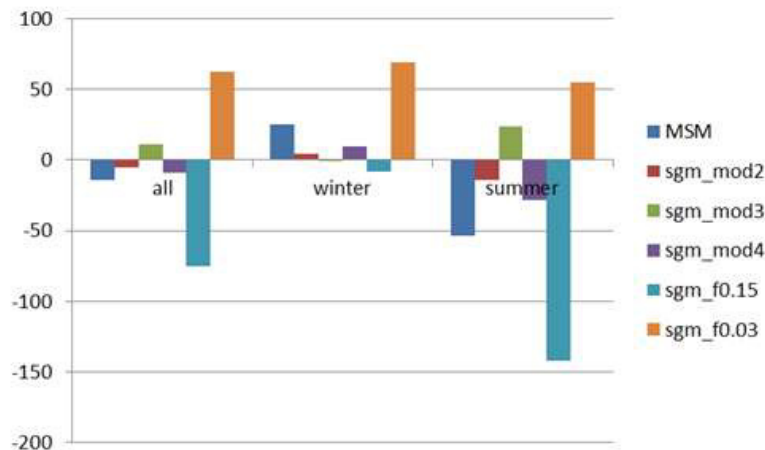


Fig. 5. The daytime averaged mean error (ME) of the MSM insolation forecast

Figure 6 shows the averaged RMSE for each case. The MSM RMSE is compared with sgm_mod2 RMSE, which is the best modification of the forecast accuracy. In the all 12 cases, 9 of them are improved RMSE but 3 of them are worse result. However, RMSE of three worse cases are about 3 W m^{-2} , which is smaller than the all-averaged improvement, so that this modification is useful method to remove the bias of the MSM cloud amount.

Figure 7 shows the horizontal distribution of cloud amount at 12JST 18 July 2010. In comparison with the satellite observation, the MSM and sgm_mod2 cloud amount is wide spread whole of the domain. In particular, the MSM and sgm_mod2 cloud amount is overestimated in the area of southwestern Japan and southeast of Japan. In comparison with the MSM and sgm_mod2 cloud amount, the cloud amount is decrease around southwestern Japan and southeast of Japan. For the further improvement of the forecast

accuracy, further modification of f_{min} or other concept is needed.

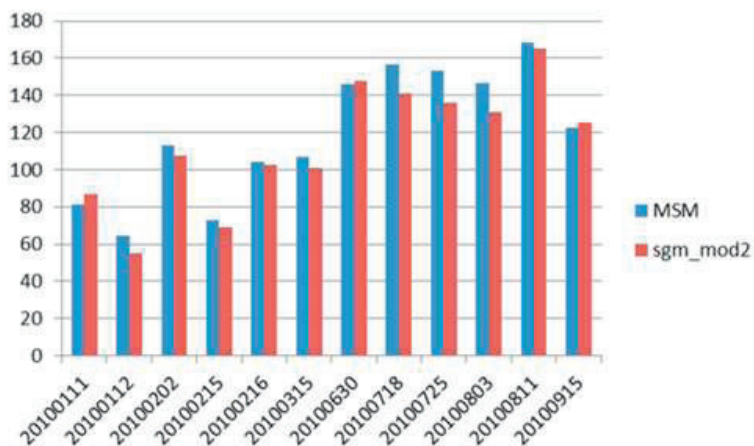


Fig. 6. The daytime averaged root mean square error (RMSE) of the MSM insolation forecast for each cases of smg_mod2

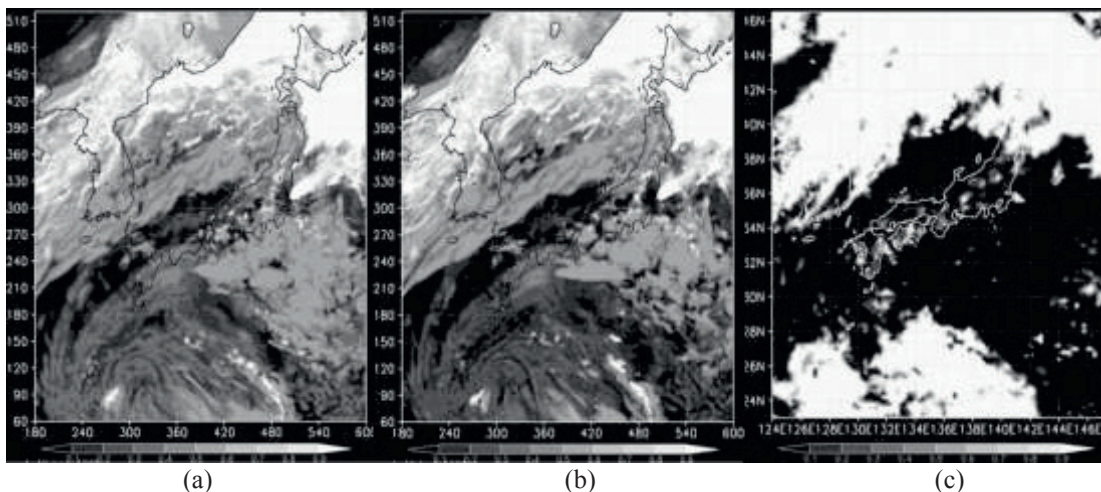


Fig. 7. Horizontal distribution of cloud amount at 12JST 18 July 2010. (a): MSM, (b): smg_mod2, (c): satellite observation

5. Conclusion

In order to reduce the MSM GHI forecast error which is in a relation of the inverse correlation with the MSM cloud amount forecast error, the new parameter is introduced into the MSM cloud process. The modified cloud scheme makes a success of the reduction of the MSM GHI forecast error (5% improvement). For the future work, the verification of long period (one month for summer and winter) will be planned.

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